2^{ND} YEAR MONITORING SFH SULZER

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ABSTRACT

The single family house (SFH) Sulzer in Schaffhausen has been retrofitted over a period of three years, starting in 2010 with the improvement of the facade insulation and later on by integrating two photovoltaic systems on the roof and a solar hybrid system at the facade. In 2012, the existing gas burner was replaced by a gas driven solid oxide fuel cell unit which produces in addition to heat also electricity. A 1000 litre storage tank enables to buffer heat loads produced from the fuel cell unit. Since the fuel cell unit took up operation in October 2012, all energy flows in the house (electricity consumption, electricity production and heating energy consumption) have been measured on a 15 minute interval basis.

The evaluation of the first year monitored (1rst November 2012 until 31rst October 2013) shows that the scope of reaching a plus primary energy balance over the year could not be achieved, due to the low solar gains and the suboptimal operation of the fuel cell unit [1]. The necessary adjustments were made for the second year monitored (1rst January until 31rst December 2014), and a positive primary energy balance could be reached.

The monitoring of the house not only aims at demonstrating a low primary energy consumption and low greenhouse gas emissions, but also at analysing how the new system affects the electricity grid and compare it with alternative heating systems such as heat pumps. In fact, fuel cells especially relieve the electrical grid during winter season, when the grid overall load is at high level.

In the coming years, the aim of the project is to further develop the internal energy system of the house in order to meet requirements of the local electrical and gas grid, without losses of user comfort. For this purpose, a power storage device will be integrated in addition to the thermal storage tank to regulate the demand from and supply into the electrical grid. According to the daily forecasting of the system services of the electricity grid, the time flexibility between production and consumption (storage) shall be used to meet the grid's requirements. On a small scale, the single family house Sulzer demonstrates a first pilot energy hub.

Keywords: monitoring, plus energy house, load management

INTRODUCTION

The SFH Sulzer located in Schaffhausen, Fernsichtstrasse 20, was constructed in the 1930s. The house was enlarged in the 1970s in its southern part and presents nowadays an overall energy reference area of about 250 m^2. The SFH Sulzer has been retrofitted over the last few years according to the following steps:

<u>1. Increase of the passive solar gains and retrofit of the envelope.</u>

First, the windows facing south-east were enlarged in order to enhance the passive solar gains. Double-glazed windows were replaced by enlarged triple-glazed windows. Thereafter, the newer annex and the basement were insulated and the thermal bridges between the annex and original part of the building were removed. Finally, due to physical constraints, a curtain-type façade was added to the original part of the building to improve the u-value. The u-values of the walls are less than 0.15 W/m^2K and the u-value of the roof is less than 0.12 W/m^2K.

2. Integration of active solar energy systems (thermal and electrical)

A photovoltaic system (5.6 kWp, el), oriented south-east on the roof, and a hybrid solar system (2.4 kWp, el) at the south facade were installed. The two different orientations and inclinations of the solar plants generate diverse production profiles, enabling a maximum of direct use of the produced electricity. Throughout the use of solar energy, the house does not only play the role as a consumer but also as a producer - hence, the building evolves to a 'prosumer'.

3. Substitution of the heating system

The old condensing gas heater and boiler installed in 1990 were replaced by a solid oxide fuel cell unit. Fuel cell heating systems produce heat and electricity by means of a chemical reaction between hydrogen, gained from natural gas and oxygen. The fuel cells cover a base load (1 kW electrical and 2 kW thermal energy) whereas the supplement burner (4- 19 kW heat power) covers the thermal peak load.

Figure 1: SFH Sulzer before the retrofit (left) and after the retrofit (right).

All energy flows (electricity consumption, electricity production and heating energy consumption) were measured on a 15 minute interval basis in the house, since the fuel cell unit started its operation at the beginning of October 2012. The aim of the monitoring was to identify energy saving potentials and to improve the overall efficiency of the house. Furthermore, the designed energy system "fuel cells and solar systems" (FC & Solar) shall be benchmarked with alternative systems; a conventional gas burner with an overall efficiency 0.95 (GB & Solar) and a heat pump system with a coefficient of performance of 2.5 or 4.5 (HP & Solar COP 2.5 – 4.5)[1]. Primary energy consumption and greenhouse gas emissions were evaluated for all systems. The monitoring of the house not only aims at demonstrating a low environmental impact but also at showing how the different technologies affect the electricity grid in terms of peaks loads.

METHOD

Monitoring of the 1st year

The measured energy flows of the 1st year monitored (1st November 2012 until 31st October 2013) were documented and compared with the projected values. The monitoring of the 1st year was used to optimise the energy system and hence improve the operation of the 2nd year. The following statements show the three most important points during the 1st year monitored:

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[1] *The range of COP chosen represents the options of heat pumps from air-to-water up to ground-to-water heat pumps [2].*

- The SFH Sulzer could not reach a plus primary energy balance.
- The electrical efficiency of the fuel cell dropped within the first year.
- The production of the hybrid collectors were considerably below the projected values.

Monitoring of the 2nd year

After analysing the results of the 1st year, the following measures for the 2nd year were proposed and implemented:

- The fuel cell unit was replaced by a more powerful unit.
- Once the fuel cells started, their modulation was limited to a 50 – 100% load in order to avoid the negative effects of the intermittent switch-on/off.
- The fuel cells had to operate as long as possible on a maximum load in order to reach maximum efficiency.
- The conflict between the usage of the fuel cell's waste heat and the thermal energy production of the hybrid solar system during the summer season had to be solved by a more effective energy management.

The optimisation measures mentioned above lead to an improvement of the overall energy balance and environmental impact.

RESULTS

Net energy consumption

Before the retrofit, the energy consumption of the SFH Sulzer was around 40'000 kWh/a (160 kWh/m^{2}a), according to the invoices of the local energy supply company [3]. After the retrofit of the building envelope, as a first step, the energy consumption could be cut in half (-49%). Electricity consumption remained constant over the last years at around 2'750 kWh/a (11 kWh/m^{2}a), see figure 2. The net energy demand was still covered by the gas heater and electricity from the grid.

The second retrofit step was to substitute the heat burner by a fuel cell and to integrate solar systems into the building's envelopes. The heat demand could be covered by the fuel cell unit and a smaller part by the hybrid collectors. The produced electricity by the fuel cells and solar systems exceed the consumption by far (460% of the consumption). The excess electricity is supplied into the grid. The gas consumption was reduced by 48%, despite the fuel cells' production of electricity. Due to the operational optimisation, additional 7% reduction of the energy consumption could be achieved in the 2nd year. The new replaced fuel cell unit could reduce gas consumption by 18% compared to the 1st year, due to the higher unit efficiency and the more effective energy management.

Final and primary energy consumption

The final and primary energy consumption of the 2nd year monitored is showed in figure 3. The primary energy consumption was evaluated both according to the Swiss and according to the European electricity mix [4] in order to differentiate the statements of the results.

Gas is mainly used in winter for space heating, hot water and electrical production, whereas in summer, hot water is partly produced with gas and thermal solar energy. The electricity supplied to the grid is fairly constant over the year. The summer peak of supplied solar energy could be flattened out. According to the Swiss electricity mix, the building consumes more primary energy than it produces (+ 1'745 kWh/a, +7 kWh/m^{2}a)). However, the building produces more primary energy than it consumes (-2'313 kWh/a, -9 kWh/m^{2}a) according to the European electricity mix.

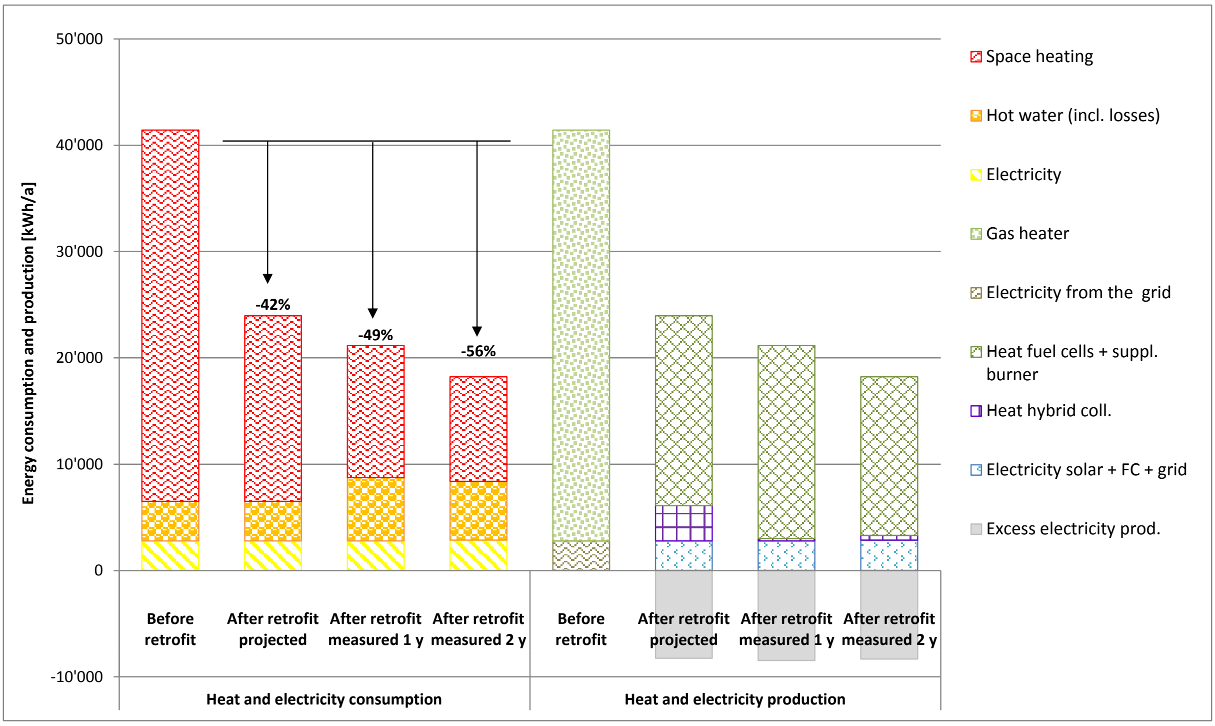

Figure 2: Net energy consumption and production before the retrofit of the house, the projected energy consumption after the retrofit and the measured energy consumption and production of the house after the 1st and 2nd year monitored.

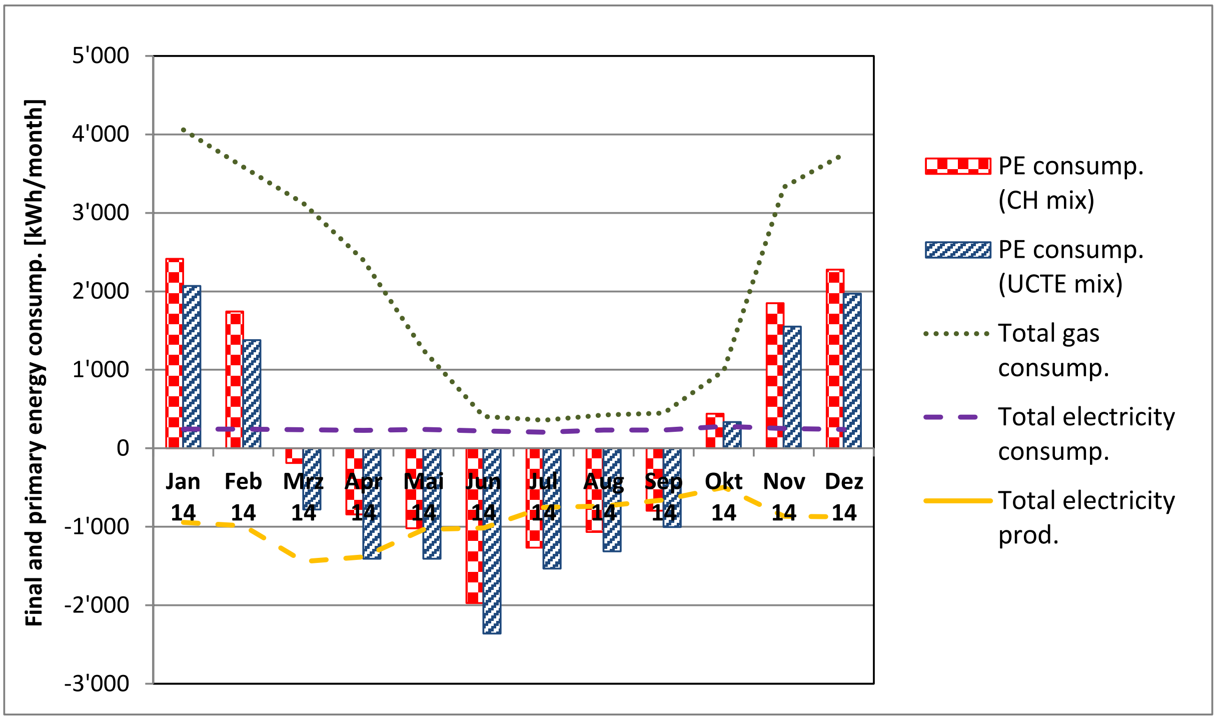

Figure 3: Final (lines) and primary (bars) energy consumption of the SFH Sulzer in the second year monitored.

Comparison: FC & Solar, GB & Solar, HP & Solar (COP 2.5 – 4.5)

The yearly primary energy consumption and greenhouse gas emissions were assessed for the four defined heating systems,: Fuel cell unit and solar systems[2] (FC & Solar), conventional gas unit and solar systems (GB & Solar) and heat pump unit and solar systems (HP & Solar (COP 2.5 – 4.5)), see Figure 4.

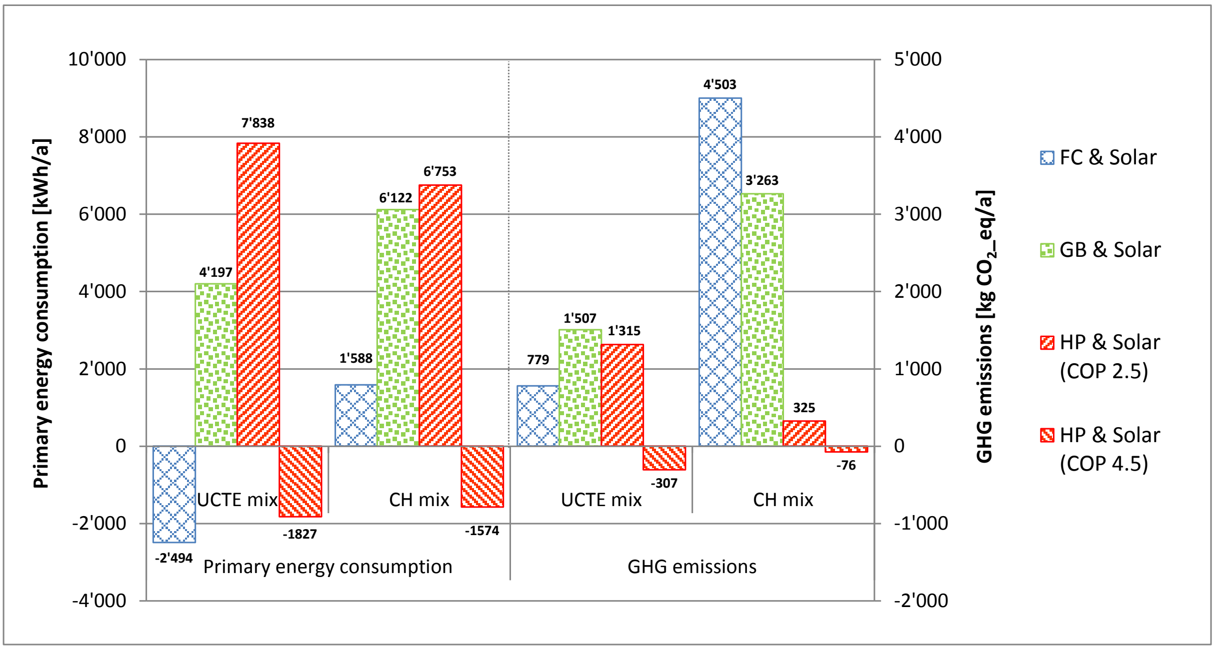

Figure 4: Comparison of different heating systems FC & Solar, GB & Solar and HP & Solar (COP 2.5 – 4.5) for the second year monitored.

The analysis of the different heating systems shows that the impact of the applied environmental factors according to the energy mix is tremendous and influences the statements essentially. According to the European electricity mix, the FC & Solar alternative presents the best option in regards to primary energy consumption and reaches the second best result on GHG emissions. The fuel cells show a low primary energy balance in the Swiss context but high greenhouse gas emissions compared to the other alternatives.

Electricity network load

The building's electrical load profile is characterised by a base load production during the heating season and solar peaks all year long. About 60% of the electricity consumption (1'800 kWh/a out of 3'000 kWh/a) is directly covered by the decentralised power units and 40% is covered by the grid. On the other hand, the grid load profile of a heat pump and solar systems (HP & Solar) is characterised by high electrical peaks during the winter season (heat pumps) and high peaks during the summer (photovoltaic). Assuming the two concepts (FC & Solar and HP & Solar) are combined in a neighbourhood, the electricity grid will benefit from a peak shaving induced by the two houses' concepts. Figure 5 shows the calculated electrical load profile of the combined concepts and indicates the possible peak reduction.

The analysis shows that the combination of the two heating systems possibly reduces the demand peak by 44% and the supply peak by 15%, compared to a sole concept.

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[2] The considered solar systems remain exactly the same among the compared heating systems

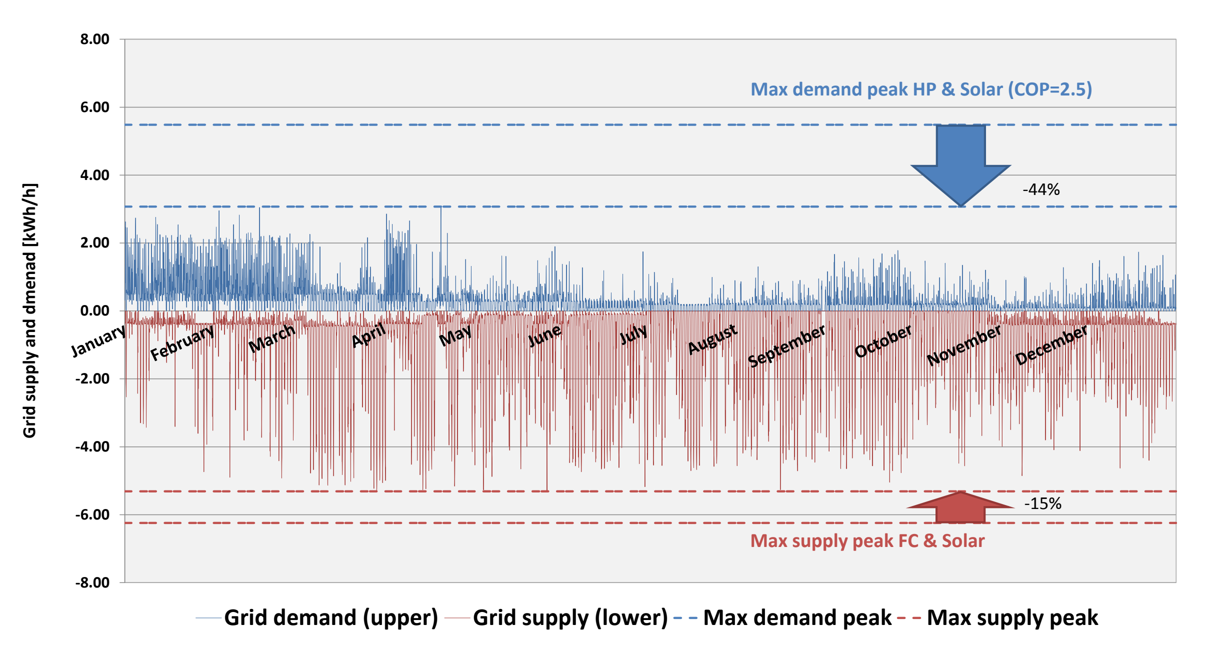

Figure 5: Grid demand (blue) and grid supply (red) of the combination: FC & Solar and HP & Solar (COP = 2.5).

DISCUSSION

The analysis of the 2nd year monitored showed the positive impact of an operational optimisation. The results are satisfying since a negative primary energy balance (considering UCTE electrical mix) could be reached for the retrofitted building. The replacement of the fuel cell unit along with its higher efficiency and more effective energy management were the key measures. This project shows once more the importance of monitoring sophisticated solutions in order to reach the planned and promised goals.

After more than two years of monitoring the building, there are still research questions left unanswered for an effective operation of fuel cells. First of all the environmental impact assessment should be calculated by hourly, daily or monthly factors, according to the current energy mix supplied by the grid. Secondly, buildings shall not only reach a low environmental impact but also be automated to serve the requirements (supply and demand management) of the gas and/or the electricity grid without losses of the user comfort. For further research, a battery pack will be installed in the house in addition to the thermal storage. The building's energy flexibility shall be analysed regarding real technical, economic and ecological benefits, on hourly, daily or monthly basis. The building will be further developed to a small scale energy hub and hence prove such concepts which could be scaled up for quarters and areas.

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